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THE NEW MAIN RING ABORT SYSTEM

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I. INTRODUCTION

The basic design of a new single-turn Main Ring beam abort system was formulated in February 1980; it was designed to operate up to a beam energy of 400 GeV. When the Tevatron becomes operational, the Main Ring will normally accelerate to only 150 GeV. In view of the limited running time remaining at 400 GeV and other considerations, it has been decided to consider an abort system of reduced capability. The purpose of this report is to give a description of the system and explore some of the options available.

II. BASIC SCHEME AND ABORTED BEAM ORBIT

By its nature, any practical beam abort system will generate substantial induced radioactivity; it is clearly desirable that this activity be located outside of the main accelerator tunnel. In order to be as "foolproof" as possible the system should be fast-acting; one is naturally led to single-turn beam extraction to an external beam dump. Since the Main Ring and Tevatron circulating beam closed orbits are everywhere within 26 inches of each other it makes sense that they share a common beam dump.

The basic elements of a single-turn extraction system are: (1) a fast-rising kicker magnet (full aperture) which displaces the beam into an extraction channel, and (2) an extraction channel, the first element of which is a septum magnet. (In principle it could all be done with full aperture kickers, but at much greater expense.) If the septum magnet is of the current sheet type it bends in the same plane as the kicker, if of the Lambertson type it bends in the orthogonal plane. (An additional drawback of the current sheet septum is that it must be pulsed and therefore would tend to degrade the response time of the abort.) The abort system differs from a standard extraction system in that it must continuously track the beam energy, starting at 8.9 GeV/c; hence it must have large aperture like an injection system and high momentum capability like an extraction system.

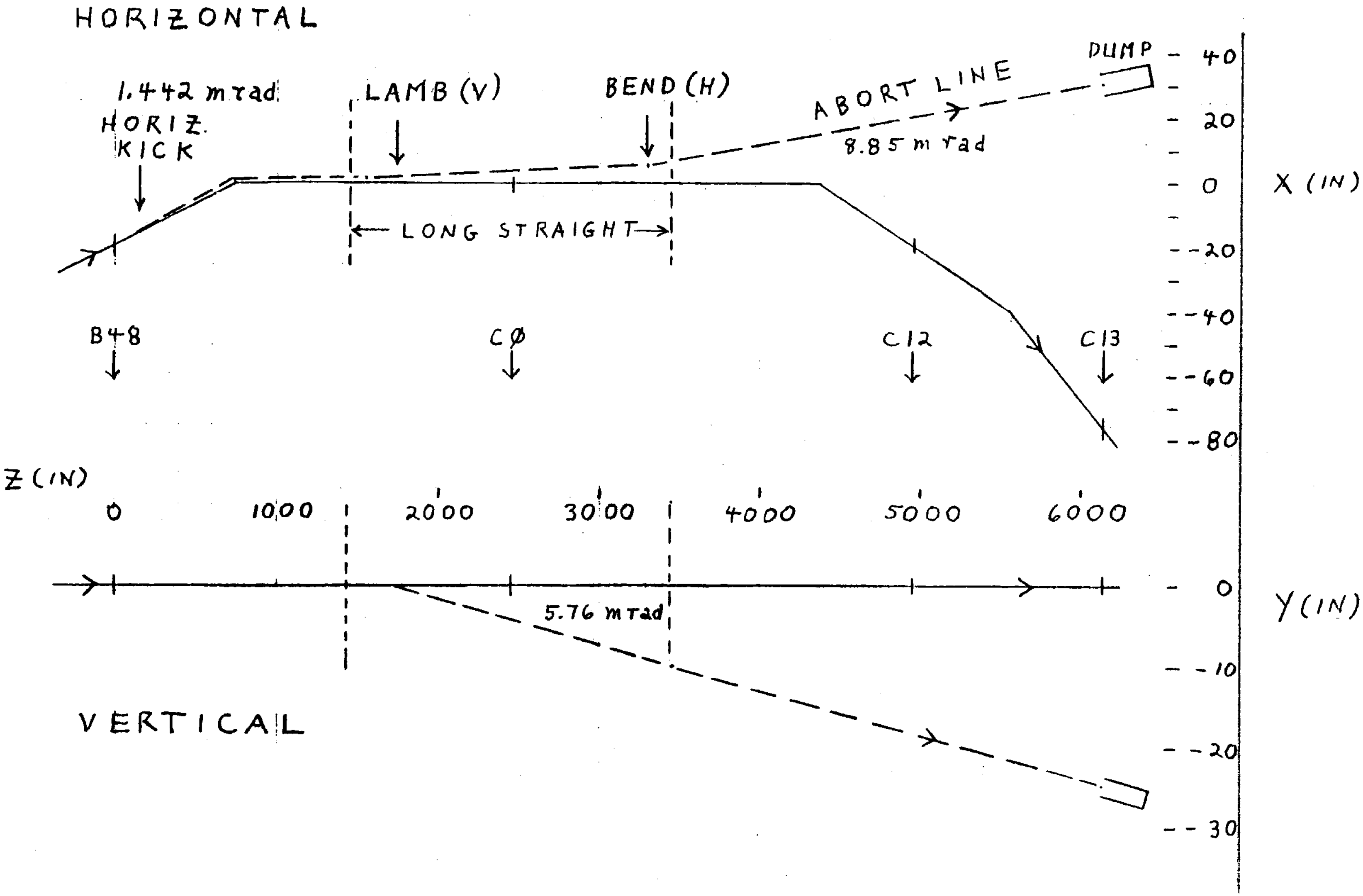
Given the constraints of the Main Ring lattice, the beam emittance, the fields obtainable in kickers and septum magnets, and the desire for a foolproof and efficient system (e.g., ≥90% extraction efficiency at 8.9 GeV/c), one concludes that the kick must be in the horizontal plane. The cross section of Main Ring quadrupoles (22 3/4 in. x 16 3/4 in., H x V) and the desire to share a common dump with the Tevatron argues for a vertically deflecting septum.

The circulating beam and aborted beam orbits are shown in Fig. 1. The abort beam line is taken out at the CØ long straight section, a choice dictated by Tevatron requirements. The beam dump[1] has been placed just outside the Main Ring tunnel at C13; a location determined by the following considerations: (1) the abort line exits the tunnel at C12 where the tunnel diameter decreases from 12 ft to 10 ft, (2) placement as close as possible to CØ straight section (minimizes excavation work) consistent with adequate radiation shielding between dump and components in the tunnel. A horizontal kick of +1.44 mrad (outward) is given the team 14 ft downstream of the B48 quadrupole, resulting in a 39 mm radial outward displacement of the beam entering the CØ straight with an angle of +2.03 mrad. A vertical Lambertson magnet septum begins at 106 in. into the long straight (x-axis radial out, y-axis vertical up, septum occupies x = 25 to 27 mm), at this

FIG 1

MAIN RING BEAM ORBITS

B48 TO C13



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location the kicked beam center is at x = 44.5 mm. The Lambertson bends the beam downward by 5.76 mrad in order to clear the vertical half-height (8.375 in.) of the first quadrupole at the end of the long straight. In oı to exit the tunnel at C12 a horizontal bend of +6.82 mrad is made at the downstream end of CØ straight. At the C13 dump the aborted beam line is 24.1 in. below the plane of the Main Ring and 105 in. outside of the normal closed orbit. The dump core[1] is a 6 in. x 6 in. column of graphite, 175 in. long.

What is somewhat unusual in this system is the relatively large kick amplitude of 1.44 mrad; at 400 GeV it requires 19.2 kG-m. For the space available at B48, ~6m, fields of 3kG are needed. In the Tevatron,[2] in order to achieve a high extraction efficiency (>99%) for the aborted beam, a 1.7μs gap is left in the circulating beam (12 instead of 13 Booster cycles to fill Main Ring) to allow for the rise time of the kicker. The solution adopted there is to use resonant charging of a lumped inductance kicker[3] with a 1.5μs rise time; it has the virtue of reducing the pulsed energy requirement by a factor of 13. It also permits the use of relatively cheap tape wound iron cores compared to ferrite. It was decided to use a similar kicker system for Main Ring and, if operating with a full ring, to accept the reduced extraction efficiency (~95%). In contrast, the abort system[4] now in use in Main Ring takes ~5ms to abort the beam and captures only 50% of the beam energy in the dump block. The new system should abort the beam in less than 100μs.

III. APERTURE CONSIDERATIONS

There are two concerns to be studies here: one is to ensure that the devices added to the Main Ring (kicker and Lambertson magnets) do not hamper normal operation of the ring (i.e., injection, acceleration, and extraction), the other is to see that there is adequate aperture in the abort line to cleanly transport the beam to the dump.

With regard to the first matter, there is a good reason to try to minimize aperture at the kicker, the transverse dimension in the field direction determines the peak pulse current needed (10-15kA) and the other dimension then determines the pulse energy required (and for a given rise time, the pulse voltage needed). Minimum aperture requirements are in general not determined by beam emittance alone but rather by some combination of emittance, closed orbit errors, injection errors, beam motion during acceleration, and resonant extraction. Due to the inherent complexity of the situation, it was decided to take the experimental approach. A set of movable beam scrapers (horizontal and vertical) were installed at the kicker location near B48 and a series of measurements[5] were carried out to determine the aperture used during normal operation of Main Ring. The measurements showed that the minimum non-interfering aperture was 56 mm x 19 mm (H x V); if in addition one desires to avoid making it a loss point (i.e., intercept stray beam which would normally hit somewhere else around the ring) the minimum aperture increases to 60 mm x 19 mm, where the horizontal aperture is asymmetric around the beam center, viz. +38 mm and -22 mm. The beam vacuum chamber in the kicker magnet is a high-purity alumina ceramic tube of elliptical cross section, the axes of the inside dimensions where specified to be 86 mm x 38 mm.[6] The other "threat" to Main Ring

FIG 2

BEAM ENVELOPES

UPSTREAM END OF CØ

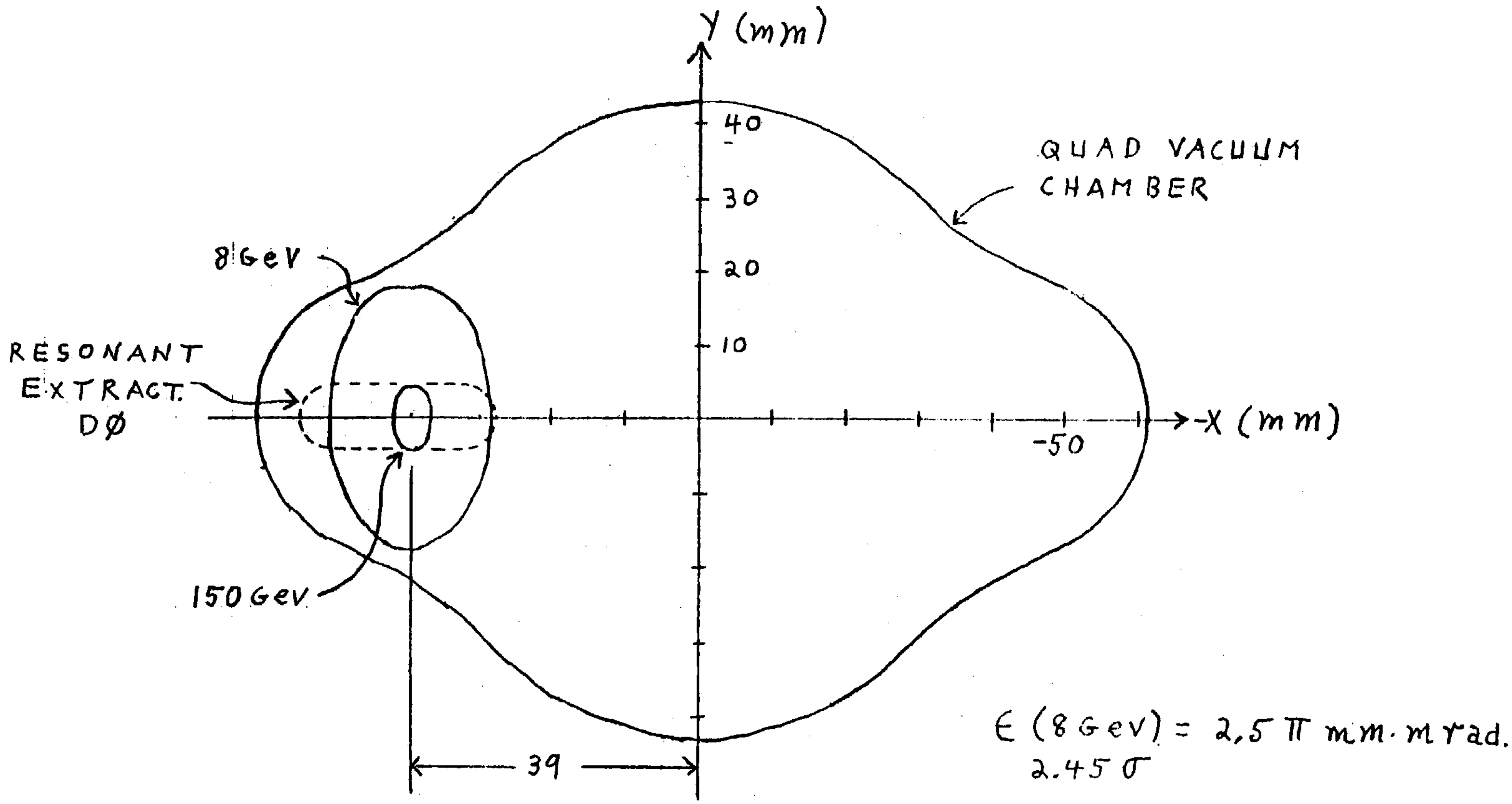

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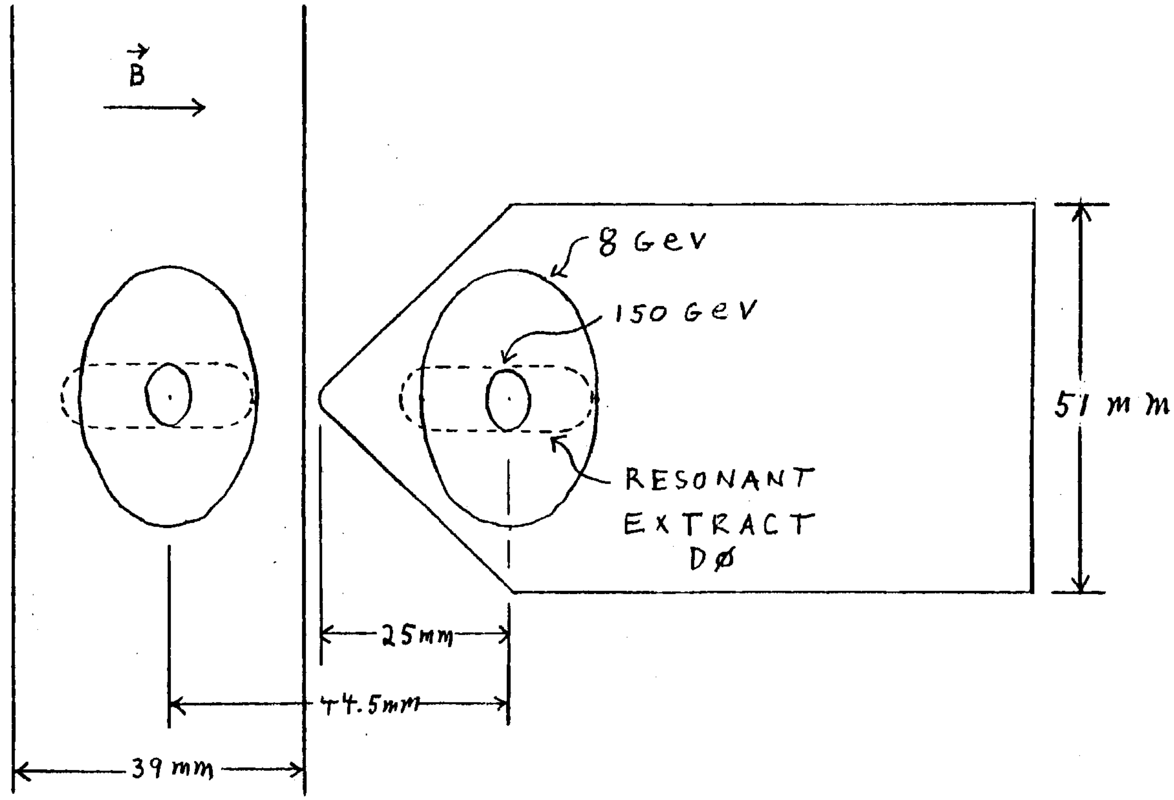
FIG 3

BEAM ENVELOPES

LAMBERTSON - UPSTREAM

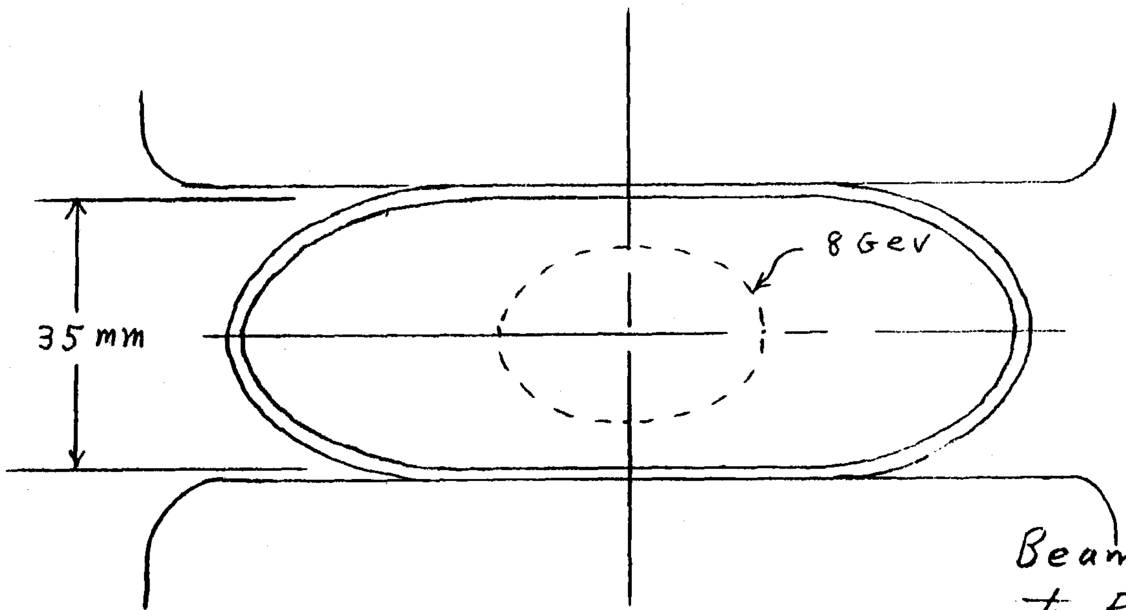


ϵ(8 GeV) = 2.5 π mm-mrad
2.45 σ

FIG 4

BEAM ENVELOPE

HORIZ. BEND, UPSTREAM



Beam at entrance to EPB Dipole

$\epsilon(8\ \mathrm{Gev}) = 2.5\pi\ \mathrm{mm \cdot mrad}$

2.45σ

operation is the horizontal position of the Lambertson septum, x = 25-27 mm. The geometry and beam envelopes at the septum are given in Fig. 3. The Lambertson in AØ used for normal extraction has a similar radial position and the same lattice functions (except it is 6.47 Betatron oscillations upstream). The main difference is that the AØ magnet has a 33.5° Lambertson angle (angle of the steel at the hole), whereas the one proposed here has a 45° angle. As can be seen from Fig. 3, closed orbit errors of +4 mm in x or ±4 mm in y will begin to give scraping (Δx = +2.3 mm combined with Δy = ±2.3 mm will also lose beam). For resonant extraction the two locations are clearly not equivalent. Calculation[7] indicates that the beam during resonant extraction (DØ septum) reaches to +15 mm; scaling this by the factor 1.32 observed in Ref. 4 gives 20 mm, or 5 mm for the septum at CØ.

The transverse beam emittance, ε_T; used here in plotting beam envelopes is 23.7π mm mrad (invariant, corresponding to an "unnormalized" $\varepsilon_T = 2.5\pi$ mm mrad at 8 GeV kinetic energy). It is the emittance (assumed Gaussian) which contains 98.6% of the beam when projected onto the x (or y) coordinate; at 8 GeV it corresponds to $\sigma = 6.45$ mm at $\beta = 100$ m. In this model an ε_T which contains 90% of the beam in a projection would be 1.13π mm mrad.[8,11] The beam scraper experiment[5] at B48 measured an aperture requirement of 36 mm x 19 mm at 8 GeV (~0.2% beam loss at 2.1 x 10^{13} ppp injected) whereas $\varepsilon_T = 2.5\pi$ mm mrad yields a size 32 mm x 17.5 mm at B48, in reasonable agreement.

Turning to the second concern, Figs. 2,3 and 4 exhibit the aborted beam envelopes and the apertures at the critical points, viz. at the exit of the last Main Ring quad upstream end of CØ, at the Lambertson entrance, and at the entrance of the horizontal bend (shown as an EPB dipole) respectively. The smallest clearance (±2.5 mm in y) occurs for the 8 GeV beam at the exit of the quad.

IV. REDUCED CAPABILITY SYSTEM

In a memo[9] of January 28, 1981, the following guidelines were set down for a Main Ring abort system of reduced scope:

1. the system be designed and built to operate at 150 GeV
2. "spare" components be installed on initial installation in order to allow operation up to ~225 GeV, including slow extraction
3. the system remain operational at 150 GeV if one of two devices of a given function fails
4. the system be upgradable to 400 GeV/c
5. the system be implemented as cheaply as possible.

In the next section we review the parameters of magnets which are candidates for such a system as a prelude to proposing and evaluating a specific possible system.

V. PARAMETERS OF CANDIDATE MAGNETS

A. Kicker Magnet. The parameters of the kicker magnet module for the Tevatron (vertical kick) abort system[3] are:

B_{max} = 3kG, rise time (0-90%) = 1.5μs

I_{max} = 18.9kA, V_{max} = 46.4kV

L = 1.258μH/m, Core length = 72 in.

Flange-to-flange = 87 in., Gap = 3.125 in.

$\Delta B/B$ (in 21μs) <10%

For the horizontal kick in Main Ring the gap becomes 2 in. but the effective pole top width becomes larger, leading to L ~2.5μH/m; for

TABLE I

DESIGN PARAMETERS OF MAIN RING ABORT LAMBERTSON MAGNET

Central Field & Aperture	
B_{max}	8.80kG
NI	29.9kA-turns
AMPFAC	1.01
GAP	
pole-to-pole	1.625 in.
total	1.665 in.
Coil Aperture	8.75 in.
Field Aperture	+1 in./-3 in. (±1%)
Coil	
I_{max} (RMS)	776a
Turns	12
Cu Conductor	.460 in. x .460 in.
Hold Diameter	.255 in.
Cu Area	.1529 in.^{2}
Resistance (50°C)	24.1 mΩ
Inductance	4.1 mH
Voltage Drip	18.7V
Power	14.6kW
Water Paths	2 (5½ turns)
Flow (80 psi)	2.02 GPM (2 x 5½ turns)
Temperature Rise	25°C
Insulation	
turn-to-turn	3kV
turn-to-core	3kV
Inputs	Both ends (2 coils, 8 terminals)
Cu weight	241 lbs

TABLE I (cont'd)

<u>Core</u>	
Iron Length	
holed pole	189 in.
solid pole	183 in.
Septum Thickness	0.08 in.
Lambertson Angle	45°
Lambertson Hole	2 in. x 3.688 in.
Iron Weight	lbs
Flange-to-Flange	191.75 in.
Lamination Thickness	.037 in.
Magnet Steel Type	
Outside Dimensions	12.125 in. x 18.812 in.
<u>Vacuum Chamber</u>	
Aperture at Ends	
hole region	Full
field region	±0.762 in. (W.R.T. midplane) +1.25 in./-3.0 in. (W.R.T. Lambertson hole)
Assembly Drawing No.	0451-MD-85269

TABLE II
EPB DIPOLE PARAMETERS

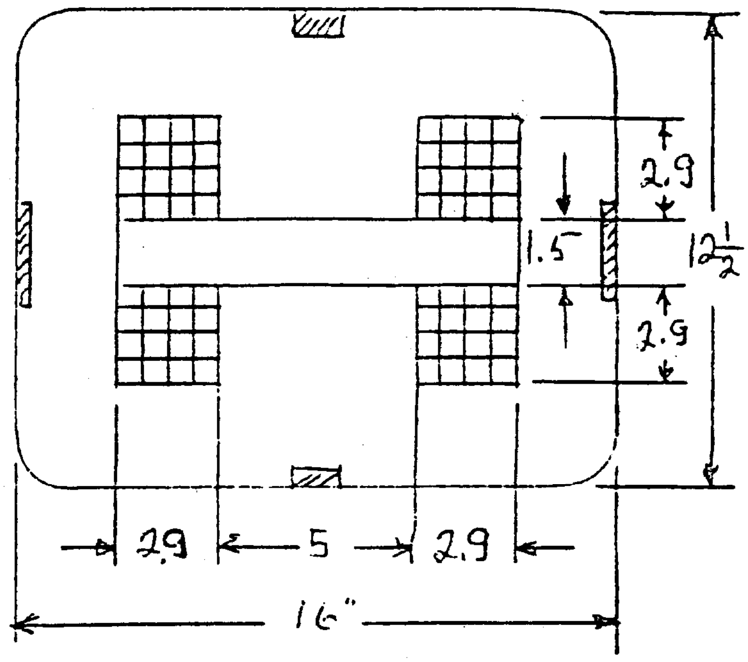
MAGNETIC FIELD	
CENTRAL FIELD	15 Kg
GOOD FIELD @ 15 Kg	3"x1.5"
POWER:	
Dc Power*	50 kw
Current*	1688 A
Voltage†	29.5 V
Copper Temp. Ave.*	130°F
Resist @ Temp*	16.0 mΩ
Time Constant	– –
Inductance*	30.0 mH
COOLING:	
Water Temp. Rise†	80°F
Total Flow†	4.72 GPM
Pressure Drop*	100 PSI
COIL DATA:	
Conductor O.D.	.0625" SQ.
Hole Diameter	0.250" DIA.
Turns	32 = (2RH + 2LH) 8/COIL
Water Paths	4 = 2IN + 2OUT
Ave. Turn Length	257"
WEIGHTS: (est.)†	
Coil & Insul.	900 #
Core	4540 #
Support	200 #
Total Magnet Assembly	5640 #
CALCULATION CONSTANTS:	
B_{kg} =	
θ_{mr} =	

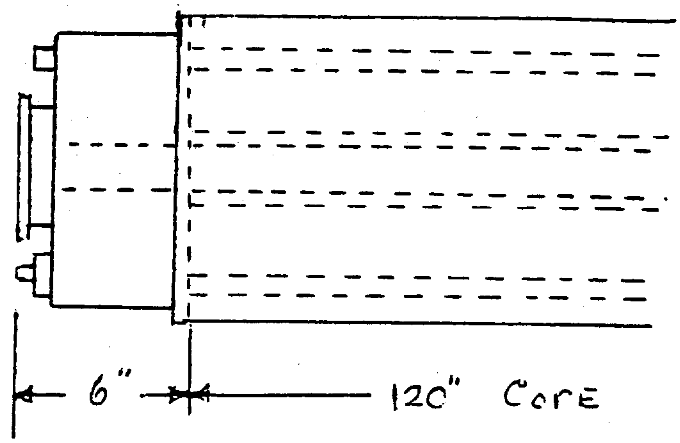
† $I_A = 112.533\ B_{kg}$

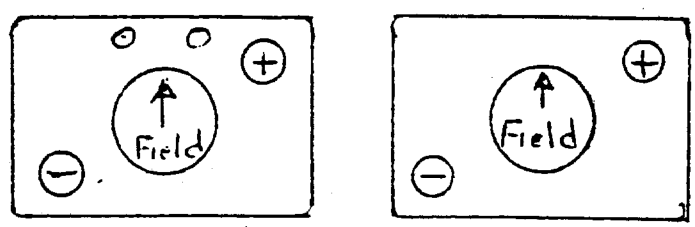
† $P_{kw} = 17.548 \times 10^{-6}\ I_A^2$

*DATA PER R. MOBLEY 17 NOV 70

†CALCULATED VALUE BASED ON * DATA







Water End

Std 6" Vacuum Flanges
Quick connection Clamp.

the same core length, field, and rise time, one gets I_{max} = 12.1 kA, V_{max} = 59kV for this kicker. At 150 GeV/c one of these modules will produce an angle (ℓ effective ~74.5 in., 5.68kG-m) of 1.135 mrad; hence two such modules would give a 1.442 mrad kick at 236 GeV/c, three at 354 GeV/c.

B. Lambertson Magnet. The parameters for a possible magnet (identical to Tevatron injection Lambertson but with gap increased from 1.0 in. to 1.625 in.) are given in Table I. The magnetic circuit allows - before saturation - B_{max} = 8.8kG, but due to the relatively small area of copper in the coil the dc field is limited to ~3kG. To obtain the desired $\Delta\theta_V$ = 5.758 mrad with two magnets requires B = 3.06kG at 150 GeV/c and 8.17kG at 400 GeV/c; the duty cycle problem will be discussed in Section VI.

C. Horizontal Bend. There are two candidate magnets for producing the 6.82 mrad bend, an EPB and a modified Main Ring B2 (modified coil end to reduce vertical half height as was done for 80 GeV extraction at F17). To allow for a 2 in. (V) beam pipe for the Main Ring circulating beam, the vertical outside dimension must be <14.3 in. A single B2 magnet clearly suffices at all energies since it bends 8.12 mrad in normal Main Ring usage. The basic parameters of an EPB are given in Table II. A single EPB at full dc power rating (50kW) will provide the needed bend at 202 GeV/c.

VI. CAPABILITIES OF SEVERAL MAGNET SCHEMES

Given the guidelines of Section IV, the orbit described in Section II and the magnet parameters described above, a system consisting of two kickers, two Lambertsons, and two EPB's appears to satisfy most requirements. Due to the average power limitation of 15kW in the

TABLE III

CURRENTS, FIELDS, CYCLE TIME VS ENERGY

CONFIGURATION (θ_V = 5.58 mR) (θ_H = 6.82)		E (GeV)	I_L (a)	B_L (kG)	I_H (a)	B_H (kG)	MIN. CYCLE TIME FTOP =	0	0.5	1.0s
1 Lamb.	1 EPB	150 200 250	1755 2340 2925	6.3 8.3 10.4	1070 1638 >2500	11.2 14.9 18.7		4.1/3.4* 8.8/3.8		9.3/4.4 17/4.7
2 Lamb.	1 EPB	150 200	877 1170	3.1 4.2	1070 1638	11.2 14.9				 4.7/4.7
2 Lamb.	2 EPB	250 400	1462.5 2340	5.2 8.3	893 1638	9.35 14.9		4/4 14.5/7	 18.8/7.5	7/5 23.3/8
3 Lamb.	2 EPB	400	1560	5.56	1638	14.9				10.4/8
2 Lamb.	1 B2'	250	1462.5	5.2	2397	9.4		4/4		7/5

*x/y   y = minimum MR cycle time in sec.

x = cycle time at which $\langle P\rangle_L$ = 14.6 kW

TABLE IV

ABORT BEAM LINE

DEVICE	ACTION (mrad)	Z_{B48} (in)	$Z_{C\emptyset}$ (in)	APERTURE+, H x V (mm)	BEAM SIZE‡, H x V (mm)	ABORTED BEAM CENTER x*(mm)	X_{49-11}	y*
B48 Quad, DS End		0	-2453.7	121 x 86 - Q	32 x 17 (56 x 4)†	0.0	-455.7	0.0
Kicker Magnet	$\Delta\theta_H$ = + 1.442							
US End		80						
Bend Center		168	-2285.6	86 x 38 - E	31 x 18 (55 x 4)	0.7	0.7	0.0
B50 Quad, DS End	(θ_H = + 2.028)	1453.0	-1000.7	121 x 86 - Q	22 x 35 (27 x 9)	39.2	39.2	0.0
Lambertson Magnet	$-\Delta\theta_V$ = 5.758							
Septum, US End		1559.3	- 894.4	39 x 152 - E	23 x 34 (26 x 8)	44.5	44.5	0.0
Bend Center		1749.7	- 704.0	(at x = 46.5)	23 x 33	54.4	54.4	- 7.01
Septum, DS End		1940.1	- 513.6		24 x 31	64.3	64.3	- 27.6
CØ		2453.7	0.0	124 x 48 - R	27 x 27 (21 x 7)	90.7	90.7	-103.0
Horizontal Bend	$\Delta\theta_H$ = + 6.820							
Core, US End	$\Delta\theta_V$ = + 0.409		712.7		32 x 23	127.5	127.5	-207.1
Bend Center		3292.4	838.7	99 x 36 - E	34 x 23	139.7	139.7	-224.9
Core, DS End	(θ_{roll} = 3.43°)		964.7		35 x 22	162.3	162.3	-242.8
C10 Quad, US End	(y_{Fe} = -213 mm)	3454.3	1000.7	124 x 48 - R	35 x 22	170.4	170.4	-247.6
C12 Penetration								
Enter Wall		4914.0	2460.6	76 x 76 - C	50 x 26	894.5	498.5	-446.0
Exit Wall			2517.0			953.7	511.2	-453.7
18" Dia. Pipe								
Starts		5053.0	2599.0	(45, - 45)x(58, - 41)	51 x 26		529.6	-464.8
Ends								
Beam Dump								
Graphite Starts		6140.0	3686.2	152 x 152	63 x 35	2661.0	773.9	-612.5
Ends			3861.0					

+Q = quadrupole shape, E = elliptical, R = rectangular, C = circular

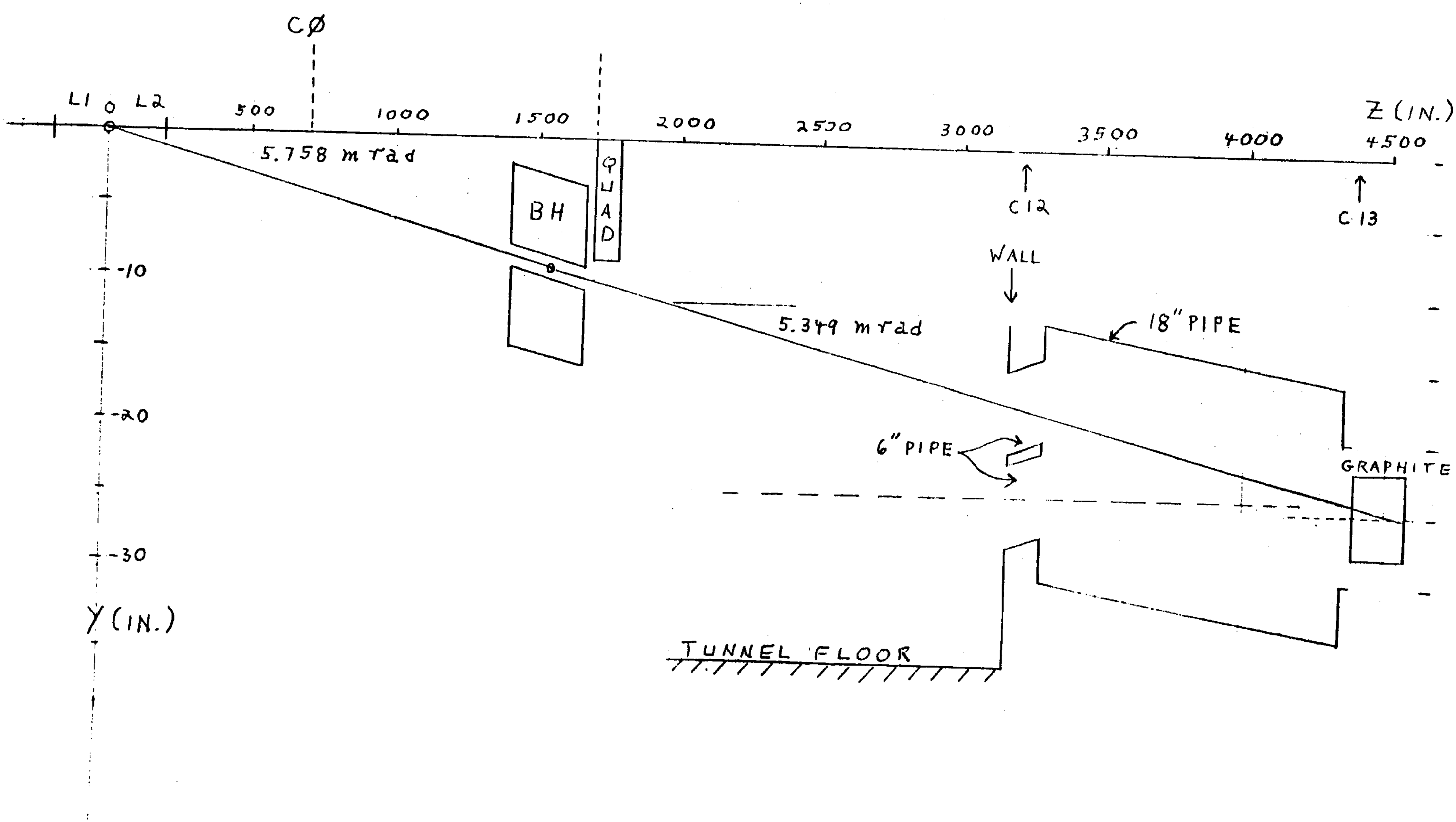
‡8 GeV Beam size, ϵ_T = 2.5π mm mrad

*Distances W.R.T. circulating beam

†Size of resonant extracted beam at 150GeV/c

FIG 5

ABORT ORBIT - VERTICAL



Lambertson, there are limitations to the maximum repetition rate for a given Main Ring ramp. Table III summarizes the rep rate limitations for ramps ranging from 150 to 400 GeV with flattops of 0, 0.5, and 1.0s, and for various combinations of magnets (adequate kicker power is assumed, see below). From Table III one concludes:

1. 2L and 2EPB is adequate up to 250 GeV, allowing a 7s cycle time with a 1s flattop. Running at 400 GeV is possible but cycle times are long (>15s).
2. 1L and 1EPB works up to 200 GeV, but a 1s flattop needs 17s.
3. 3L and 2EPB or 3L and 1B2 allows a 10.4s cycle at 400 GeV with a 1s flattop.

VII. DETAILED ABORT LINE GEOMETRY

A detailed listing of the abort line geometry sketched in Fig. 1 is given in Table IV. Starting at the kicker, it gives aperture, beam size, and the transverse coordinates of the center of the aborted beam; The specific scenario used is the "2K + 2L + 2B" one with EPB dipoles. The horizontal coordinate, x, is given in two systems: one is with respect to the circulating beam closed orbit, the other, w.r.t., the line joining the B49-CØ-C11 station marks.

An expanded view of the vertical orbit is shown in Fig. 5; starting at the tunnel wall penetration at C12, there is a 6 in. o.d. stainless steel pipe which runs through the hole bored in the wall, after 138 in. it joins onto an 18 in. o.d. pipe (in the earth outside the tunnel). Due to construction difficulties this peipe is somewhat misplaced,[10] instead of sloping downward at 5.8 mrad, it runs upward by 8.3 mrad. In order to obtain adequate vertical clearance at the 6 in. 18 in. pipe junction, magnet BH is rolled by 3.43° so as to make a $\Delta\theta_V$

FIG 6

M.R. ABORT KICKER MAGNET LAYOUT

B 48

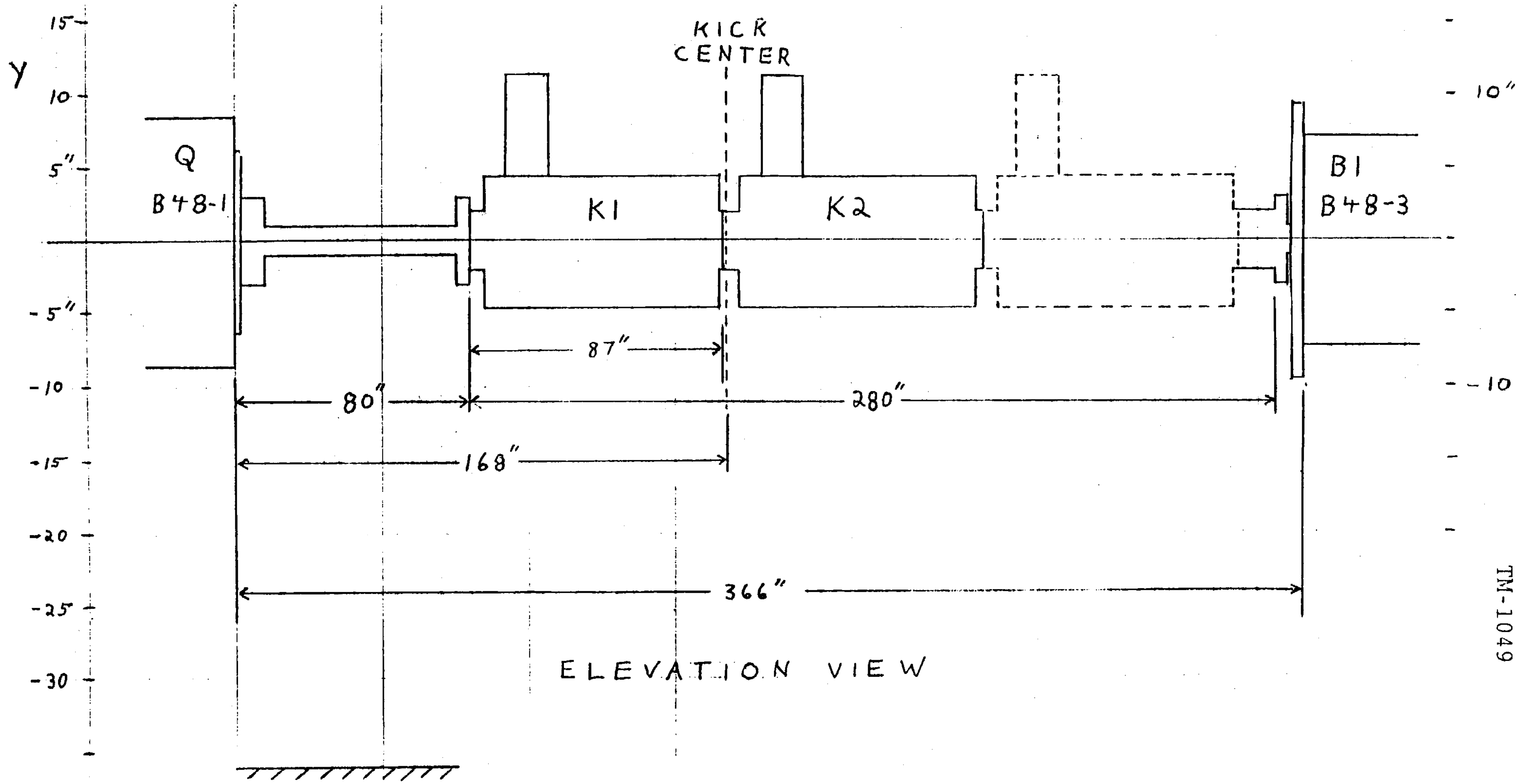
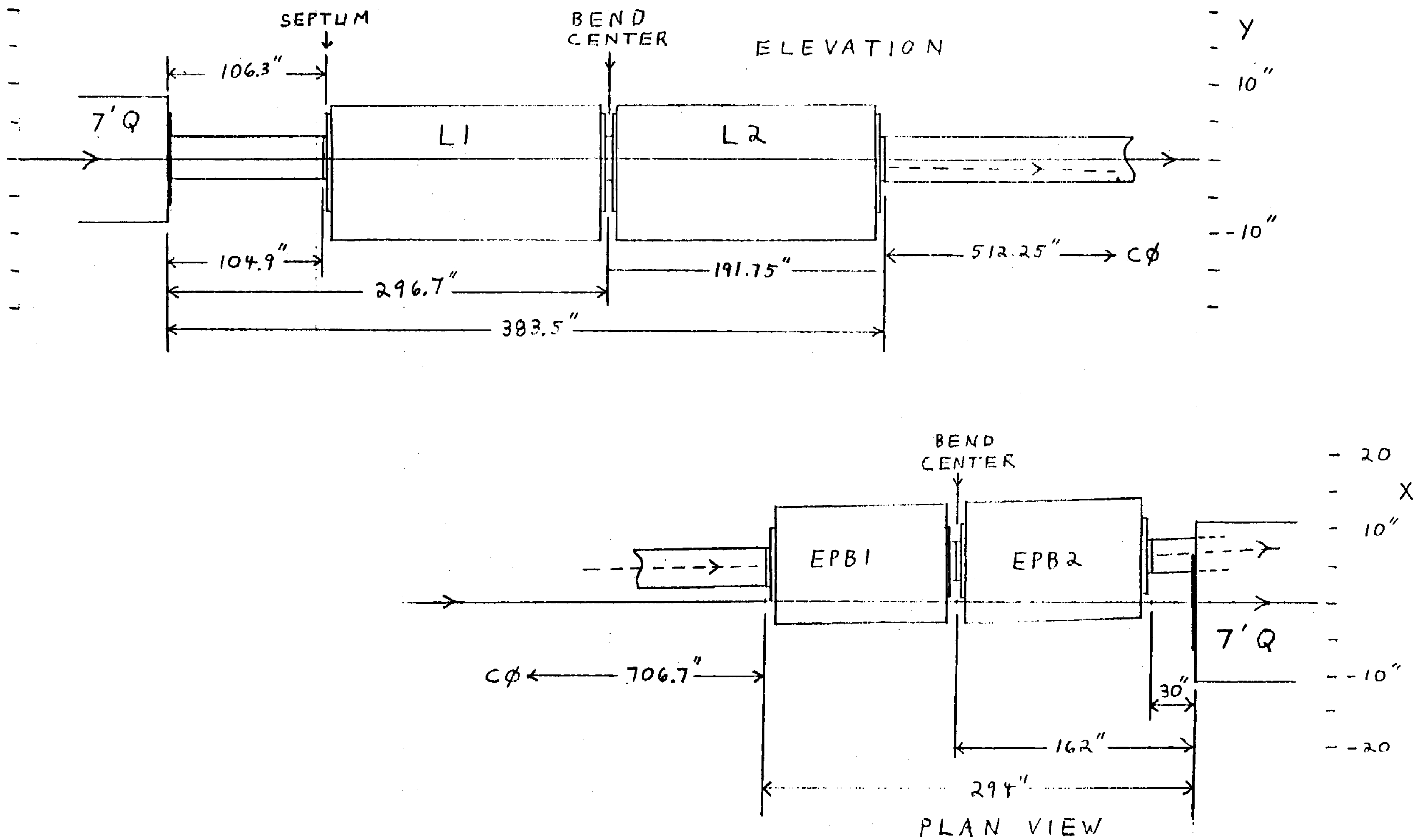


FIG 7

MR ABORT LAYOUT
CØ



of +0.409 mrad. The vertical orbit obtained in a compromise, being 0.4 in. below optimum at the junction and 0.75 in. high at the dump face. The situation could be improved a little by moving BH further downstream, about 30 in. is available.

Figures 6 and 7 show the longitudinal layout of the magnets at B48 and at CØ; the transverse coordinates can be obtained from Table IV.

VIII. 150 GeV CAPABILITY FOR A "ONE-MAGNET-FAILURE" MODE

The question here is whether one can maintain a "clean" abort channel if a single magnet fails in the 2K + 2L + 2EPB system. Beam motion at the critical apertures for single magnet is given below; the motion is w.r.t. the "standard" orbit as given in Table IV. The first column gives the motion after the first order correction (e.g., if L1 fails, double L2, for the kicker this is not possible, one kicker at 150 GeV can supply 76.6% of the standard displacement), the second column gives the residual after the second order correction.

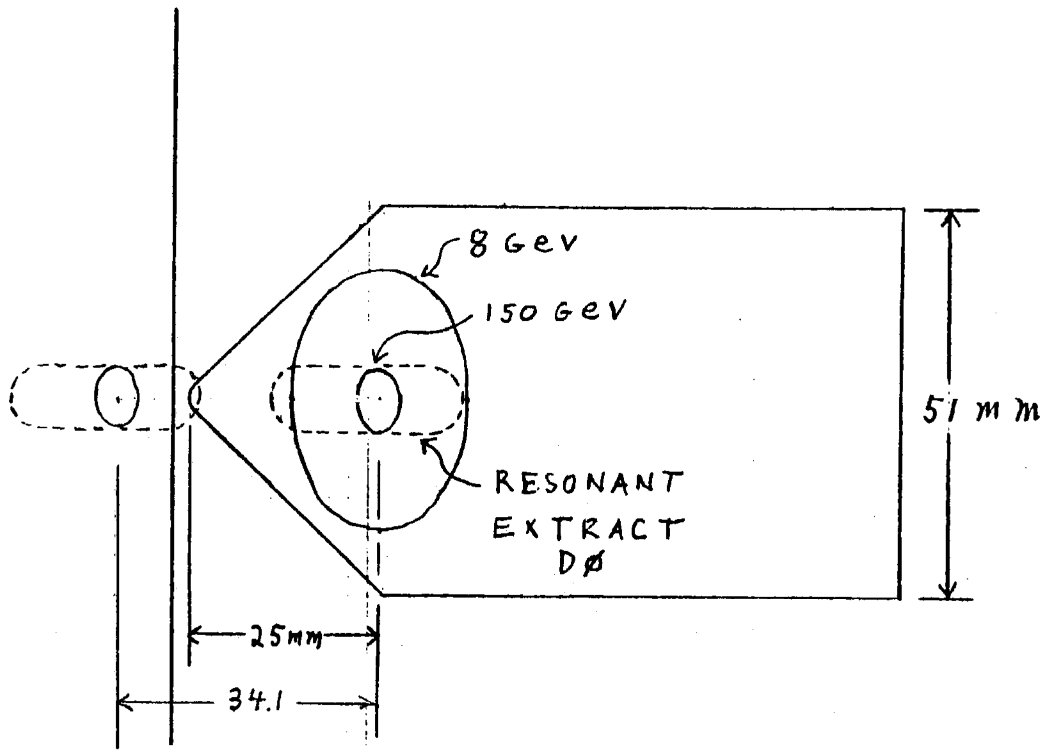
FAILURE	LOCATION	BEAM MOTION (mm)	BEAM MOTION (mm)
K1			1.103 x(BH1 + BH2)
	L1	Δx = -10.4	-10.4
	BH2	-19.2	-18.2
	18" pipe	-38.6	- 7.4
	Dump	-50.7	0.0
L1		2 x L2	2.104 x L2
	BH2	Δy = 14.0	2.0
	18"	13.5	-10.0
	Dump	13.4	-17.9
BH1		2 x BH2	2.078 x BH2
	18"	Δx = -11.4	0.0
	Dump	-11.4	7.5

FIG 8

BEAM ENVELOPES

LAMBERTSON - UPSTREAM

1 KICKER CASE



$\epsilon(8\ \text{GeV}) = 2.5\pi$ mm-mrad

$2.45\ \sigma$

As can be seen from the apertures and beam sizes in Table IV, clearances are still adequate. Figure 8 depicts the situation at the Lambertson septum with only one kicker (K2) at 150 GeV/c (the standard kick can be maintained up to 115 GeV/c); a resonant extraction beam will clip the septum, but the normal beam has a 4.3mm clearance.

Although there is some virtue to have L1 L2 in series with BH1 BH2 on the same power supply, it is clear from Table III that the currents required do not match at all well; in addition it does not lend itself to the single-magnet-failure environment.

IX. EXPANDABILITY TO 400 GeV/c

Enhancing the system to a 400 GeV capability would involve adding a third kicker magnet and a third Lambertson (see Table III). The shift in bend center at L is just that which happens in the case of L1 failure in Section VIII, hence the vertical orbit is acceptable. Three kickers will provide the 44.5 mm displacement at L1 only up to 342 GeV/c; at 400 GeV/c the displacement is only 38.1 mm. Thus at 400 GeV/c the inner edge of the slow extracted beam will just miss the septum; it would probably suffice for the slow extracted beam (tenuous tail) but not for 1ms resonant extraction. One could always add a pair of dipoles to make a 6mm orbit bump at L1.

X. CONCLUSION

A new abort system based on single-turn extraction to the newly built beam dump at C13 appears feasible. It utilizes 3kG kickers located at the B48 location together with Lambertson magnets and dipoles in the CØ long straight section. As a result of its fast-acting capability and high extraction efficiency, it will make substantial improvements to Main Ring operation.

A specific system, adapted to operation at 150 GeV/c with the Tevatron, has been proposed. The system employs two 2m-kicker modules, two Lambertson magnets, and two EPB dipoles. The Lambertsons are a slightly modified version of the type being built for injection into the Tevatron. The system could continue to function at 150 GeV/c under a failure of any one of the three types of magnets; in addition it has the capability to support operation with slow extraction (1s flattop) up to 250 GeV/c with a 7s cycle time. With the addition of one more kicker module and Lambertson, capability can be extended to 400 GeV/c with a 10.4s cycle time (1s flattop).

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REFERENCES AND FOOTNOTES

1. J.Kidd, N.Mokhov, T.Murphy, M.Palmer, T.Toohig, F.Turkot and A.VanGinneken; "A High Intensity Beam Dump for the Tevatron Beam Abort System," Proceedings of the Particle Accelerator Conference, Washington DC (1981, in press).

2. "A Report on the Design of the Fermilab Superconducting Accelerator," Fermilab (1979, unpublished).

3. G.Krafczyk, H.Edwards, Q.Kerns, M.May, E.Tilles, and F.Turkot; "A 3kG Kicker Manget System for the Tevatron Beam Abort System," Proceedings of the Particle Accelerator Conference, Washington DC (1981, in press).

4. R.Carrigan et al., "Main Accelerator Abort System," IEEE Trans. Nuclear Sci. Vol. NS-20, 240 (1973).

5. F.Turkot, "Determination of Main Ring Aperture Requirements at the B48 Location," Accelerator Division Experiment, EXP-106, Fermilab (1981, unpublished).

6. These dimensions are considerably larger than the minimum requirements at B48; the reason being that the same tube design would be used in the other devices needing more aperture.

7. Private communication with M.Harrison, January 1980.

8. Measurements made at 150 GeV in October 1979 (1.8×10^{13} ppp) using the IBS profile monitor gave a $\sigma = 1.49$ mm ($\beta = 100$ m); the corresponding σ at 8 GeV is 6.1 mm. More recent measurements in Main Ring (private communication C.Moore, April 1980) give an 8 GeV $\varepsilon_T = 0.78\pi$ mm mrad (90%, 2.5×10^{13} ppp) for the injected beam; injection mismatch increases it to 1.1π mm mrad.

9. Internal memo, H.Edwards and F.R.Huson, January 1981.

10. Private communication with T.Murphy (May 1981).

11. C.Moore, C.Curtis, J.Lacky, C.Owen, C.Ankenbrandt, R.Gerig, S.Pruss; "Dependence of the Emittances of the Fermilab Injectors on Intensity," PAC, Washington DC (1981).